Toshi Nagata[3] (81 77 549 8239; nagata@ecology.kyoto-u.ac.jp)

[1]Laboratoire d'Oceanographie de Villefranche (LOV), BP 28, Villefranche-sur-Mer 06234, France

[2]Ocean Sciences Centre, Memorial University of Newfoundland, St. John's, NF A1C 5S7, Canada

[3]Center for Ecological Research, Kyoto University, Kamitanakami-Hirano, Otsu 520-2113, Japan

Most of the biogenic carbon (BC) that is exported (E) from the euphotic zone is remineralized to CO2 (i.e. respiration, R) in the underlying mesopelagic layer (or twilight zone), which in most oceans extends to the permanent pynocline (typically ca. 1000 m). A significant part of this remineralized CO2 is ventilated back to the surface layer on decadal time scales, where it equilibrates with the atmosphere. Only the BC that is remineralized or buried below the permanent pycnocline is isolated from the atmosphere long enough to be of significance to the global climate (i.e.. sequestration, S). Current estimates of E and S for the World Ocean are ca. 7 to 12 and 1 to 2 Gt C/year, respectively. The main biological mechanisms that control R in the mesopelagic layer are the size structure, sinking velocity and chemical composition of E. The interactions among these factors are nonlinear. Because the changing climate will modify both R and the downward propagation of characteristics of the surface ocean (e.g. heat, storm mixing), these will influence S, which will in turn feedback to the climate.

OS31L-08 1050h INVITED

Influence of Mesopelagic Respiration on Biogenic Carbon Cycling.2. Rates and Patterns.

Richard B Rivkin[1] (709-737-3720; rrivkin@mun.ca); Louis Legendre[2] (+33-04-93-76-38-36; legendre@obs-vlfr.fr); Toshi Nagata[3] (+81-77-549-8239; nagata@ecology.kyoto-u.ac.jp); Heather Bussey[1] (709-737-2613; heatherbussey@hotmail.com); Paul Matthews[1] (709-737-2613; pmatthew@mun.ca); Danielle Churchill[1] (daniellechurchill@hotmail.com)

[1]Ocean Sciences Centre, Memorial University of Newfoundland, St John's, NF A1C 5S7, Canada

[2]Laboratoire d'Ocanographie de Villefranche,, BP 28, 06234, Villefranche-sur-Mer, France

[3]Center for Ecological Research, Kyoto University, Kamitanakami-Hiranocho, Otsu 520-2113, Japan

Relatively little is known about processes occurring in the mesopelagic layer (i.e. twilight zone; 100 to 1000 m). Trap studies suggest that about 90 percent of the settling particulate organic carbon (POC) is remineralized between 100 and 1000 m, but remineralization of dissolved organic carbon (DOC) is largely uncharacterised. The biogenic carbon (BC) that is transferred or buried below the permanent pycnocline (i.e. sequestration, S) is isolated from the atmosphere for long periods (e.g. millennia) and is therefore of significance to global climate change. The sequestration of BC can be computed from euphotic zone export (E) and its subsequent mesopelagic remineralization (R; S = E - R). Because there are very few direct measurements of R, we estimated this property, at the global scale, from a meta-analysis of the distributions of physical, chemical and bacterial properties in the mesopelagic layer. We computed heterotrophic respiration from empirical relationships among temperature, DOC, and bacterial production and growth efficiency. Preliminary estimates of R are 11 to 35 (mean = 22) Gt C/year for the World Ocean. These values are 28 to 88 percent of the computed upper ocean respiration of ca. 40 Gt C/y. These data suggest that global dissolved and particulate primary production may be >75 Gt/y.

OS31L-09 1105h INVITED

Respiration and organic carbon inputs to the mesopelagic ocean

Carlos M. Duarte[1] (34971611725; cduarte@uib.es)

Javier Arstegui[2]

Susana Agust[1] (sagusti@uib.es)

[1]IMEDEA (CSIC-UiB), Miquel Marqus 21, Esporles 07190, Spain

[2]Facultad de Ciencias del Mar, Universidad de Las Palmas de Gran Canaria, Campus de Tafira Baja, Las Palmas Gran Can, Spain

Respiration in the mesopelagic ocean has been traditionally considered to play a small role in the global oxidation of organic matter in the ocean. Recent evidence, however, suggests that mesopelagic respiration is likely to be comparable in magnitude to respiration in the euphotic zone. In this presentation we synthesize information on the mechanisms of transport, transformation and the rate of respiration of organic matter in the mesopelagic ocean. Finally, a respiratory carbon budget will be produced for the mesopelagic ocean, to be compared with estimates of vertical and lateral inputs of organic matter.

OS31L-10 1125h

A 1 D Size-resolved Model of Particle Dynamics below the Mixed Layer.

Lars Stemmann[1] (1-979-845-1115; stemmann@ocean.tamu.edu)

George Jackson[1] (1-979-845-1115; gjackson@tamu.edu)

Debby Ianson[1] (1-979-845-1115; ianson@halodule.tamu.edu)

Gabriel Gorsky[2] (33-4-93-76-38-16; gorsky@obs-vlfr.fr)

[1]Texas AM University, Dept. of Oceanography, College Station, TX 77843-3146, United States

[2]Laboratoire d'Oceanographie de Villefranche, UMR7093, B.P.28, Villefranche-sur-Mer 06234, France

Marine particle size structure and dynamics in the mixed layer have been intensively studied and several models including phytoplankton growth, sinking, coagulation, bacterial degradation and zooplankton grazing have been proposed. Considerably less is known in the deeper layers due to the lack of observations; in particular of particle size structure. Sediment traps data have shown that large aggregates may be a major component of POM vertical flux. Particle aggregation by coagulation and zooplankton feeding and defecation may be important. To address the question of mid-water particle transformation, we formulated a 1D model with size specific equations describing particle sinking, coagulation, disaggregation and bacterial and zooplankton consumption. The model is forced at 100 m depth by observed particle size spectra; the modeled particle size spectra are compared with observations between 100 and 1000 m depth. We use data obtained at a quasi-oceanic site for a four years time series in the NW Mediterranean Sea. The model can describe as much as 60% of the variance in particle size spectra. Inferred vertical fluxes are also compared to the vertical flux measured at 1000 m depth.

OS31L-11 1140h INVITED

Does Mesoscale Hydrodynamics Affect the Spatial Distribution of Large Particulate Matter?

Gabriel Gorsky[1] (33-4-93-76-38-16; gorsky@obs-vlfr.fr)

Louis Prieur[1] (prieur@obs-vlfr.fr)

Isabelle Taupier-Letage[2] (Isabelle.Taupier.Letage@ifremer.fr)

Lars Stemmann[3] (stemmann@ocean.tamu.edu)

Marc Picheral[1] (picheral@obs-vlfr.fr)

[1]Laboratoire d'Oceanographie de Villefranche, CNRS/UPMC/INSU, Station Zoologique, B.P. 28, Villefranche sur mer 06230, France

[2]Laboratoire d'Oceanographie et de Biogeochimie, CNRS UMR 6535, c/o IFREMER, BP 330, LA SEYNE 83507, France

[3]Texas AM University, College Station, TX 77843-3146, United States

The relationship between mesoscale hydrodynamics and the distribution of Large Particulate Matter (LPM, particles larger than 200 m) in the first 1000 m of the western Mediterranean basin was studied with a microprocessor-driven CTD-video package, the Underwater Video Profiler (UVP). Observations made during the last decade showed that in late spring and summer LPM concentration was high in the coastal part of the W Mediterranean basin at the shelf break and near the continental slope (computed maximum: 149 microgC.l-1 between 0 and 100 m near the Spanish coast of the Gibraltar Strait). LPM concentration decreased further offshore into the central Mediterranean Sea where, below 100 m, it remained uniformly low, ranging from 2 to 5 microgC.l-1. However, a strong variability was observed in the different mesoscale structures such as the Almeria-Oran jet in the Alboran sea or the Algerian eddies. LPM concentration was up to five times higher in fronts and eddies than in the adjacent oligotrophic Mediterranean waters (i.e. 35 vs. 8 microgC.l-1 in the Alboran Sea or 16 vs. 3 microgC.l-1 in a small shear cyclonic eddy).

Our observations suggest that LPM spatial heterogeneity generated by the upper layer mesoscale hydrodynamics extends into deeper layers. Consequently, the superficial mesoscale dynamics may significantly contribute to the biogeochemical cycling between the upper and meso-pelagic layers.

OS31M HC: 315 Wednesday 0830h

Equatorial Oceanography I

Presiding: **D Moore,** NOAA /PMEL**;** **J P McCreary,** IPRC

OS31M-01 0830h INVITED

Dynamics of the Pacific Subsurface Countercurrents

Julian P. McCreary[1] ((808)956-2216; jay@soest.hawaii.edu)

Zuojun Yu[1] ((808)956-8175; zuojun@soest.hawaii.edu)

Peng Lu ((305)232-5171; wowo50@hotmail.com)

[1]International Pacific Research Center, University of Hawaii at Manoa 2525 Correa Rd., Honolulu, HI 96822, United States

A hierarchy of models, varying from $2\,{}^1/_2$-layer to 4% $^1/_2$-layer systems, is used to explore the dynamics of the Pacific Subsurface Countercurrents, commonly referred to as Tsuchiya Jets (TJs). The TJs are eastward currents located on either side of the equator at depths from 200 m to 500 m and at latitudes varying from about 2° to 7° north and south of the equator, and they carry about 14 Sv of lower-thermocline (upper-intermediate) water throughout the tropical Pacific. Solutions are found in idealized and realistic basins, and are obtained both analytically and numerically. They are forced by winds and by a prescribed Pacific interocean circulation (IOC) with transport M (usually 10 Sv), representing the outflow of water in the Indonesian passages and a compensating inflow from the Antarctic Circumpolar Current.

Analytic solutions to the $2\,{}^1/_2$-layer model suggest that the TJs are geostrophic currents along arrested fronts. Such fronts are generated when Rossby-wave characteristics, carrying information about oceanic density structure away from boundaries, converge or intersect in the interior ocean. They indicate that the southern and northern TJs are driven by upwelling along the South American coast and in the ITCZ band, respectively, that the northern TJ is strengthened by a recirculation gyre that extends across the basin, and that TJ pathways are sensitive to stratification parameters. Numerical solutions to the $2\,{}^1/_2$% -layer and $4\,{}^1/_2$-layer models confirm the analytic results, demonstrate that the northern TJ is strengthened considerably by unstable waves along the eastward branch of the recirculation gyre, show that the TJs are an important branch of the Pacific IOC, and illustrate the sensitivity of TJ pathways to vertical-mixing parameterizations and the structure of the driving wind.

In a solution to the $2\,{}^1/_2$-layer model with $M = 0$, the southern TJ vanishes but the northern one remains, being maintained by the unstable waves. In contrast, both TJs vanish in the $M = 0$ solution to the 4% $^1/_2$-layer model, apparently because wave energy can radiate into a deeper layer (*i.e.*, layer 4). In the $4\,{}^1/_2$% -model, then, the TJs are in fact driven by the Indonesian Throughflow, a remarkable example of remote forcing on a basin-wide scale.

OS31M-02 0855h

Equatorial currents in nested high-resolution tropical Pacific simulations during 1992-1997.

Virginie Thierry[1] (1-858-822-5021; vthierry@ucsd.edu)

Bruce D. Cornuelle[1] (1-858-534-4021; bdc@ucsd.edu)

Detlef Stammer[1] (1-858-822-3376; dstammer@ucsd.edu)

[1]Scripps Institution of Oceanography - University of California, San Diego, 9500 Gilman Drive - MS 0230, La Jolla, CA 92093-020, United States

Using a 1/3 ° resolution model of the tropical Pacific Ocean, we investigate the structure of the surface layers (0-400 m) in the equatorial Pacific Ocean from 1992 to 1997. The model has open boundaries at 26°N, 26°S and in the Indonesian Throughflow. Boundaries conditions are prescribed from a low-resolution global model (ECCO project) which assimilates altimetry data from TOPEX/Poseidon, ERS1 and ERS2 satellites as well as monthly temperature and salinity climatologies. To study the impact of the forcing on the quality of the results, the model is driven by forcing fields estimated by the ECCO model or by the NCEP forcing files, respectively. When using the ECCO forcing, the currents at 110°W and 140°W of longitude along the equator are in a remarkably good agreement with the TOGA-TAO measurements. As a prerequisite

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to later assimilation runs, we compare the model output to ocean observations in terms of simulation of the flow field and in terms of statistics of eddy variability.

OS31M-03 0910h

The Equatorial 13°C Thermostad: Local or Distant Formation?

Frederic Marin[1] (33-2-98-22-46-89; fmarin@ifremer.fr)

Bach Lien Hua[1] (33-2-98-22-41-49; lien@ifremer.fr)

Richard Schopp[1] (33-2-98-22-49-80; schopp@ifremer.fr)

Sophie Wacongne[2] (wacongne@ocean.ocean.fsu.edu)

[1]Laboratoire de Physique des Oceans, UMR6523 CNRS/IFREMER/UBO BP 70, Plouzan 29280, France

[2]Department of Oceanography, Florida State University West Call Street, Tallahassee, FL 32306-4320, United States

A remarkable feature that is observed in both the equatorial Atlantic and Pacific oceans is the presence of an homogeneous region, beneath the thermocline, in which temperature, salinity and low potential vorticity are uniform: the 13°C thermostad. This thermostad is delimited by two permanent, symmetric eastward countercurrents, known as North and South equatorial undercurrents in the Atlantic and as Tsuchiya jets in the Pacific, which are located near 3 degrees in latitude. The current view is that 13°C waters are formed at the ocean surface in restricted subtropical areas, are subducted and advected under lighter waters and thus participate in the ventilation of the upper ocean up to the equator via the large-scale circulation, western boundary currents and pre-existing countercurrents. Alternatively, 13°C waters can be viewed as formed locally in equatorial regions by subsurface convection within meridional oceanic cells. Here, a high-resolution three-dimensional model is used to compare the two views. We conclude that local subsurface equatorial convection is tied to ventilation through the large-scale equatorward shoaling of the thermocline and induces the formation of subsurface countercurrents. Therefore a local equatorial process, triggered by a distant forcing, reconciles the two views.

OS31M-04 0925h

Sensitivity of equatorial stratification to changes in midlatitude westerly wind

Masami Nonaka[1,2] (1-(808)956-2720; nona@soest.hawaii.edu)

Shang-Ping Xie[1] (xie@soest.hawaii.edu)

Julian P. McCreary[1] (jay@soest.hawaii.edu)

[1]International Pacific Research Center/SOEST, University of Hawaii, 2525 Correa Road, Honolulu, HI 96822, United States

[2]Frontier Research Center for Global Change, 3173-25, Showa-machi, Kanazawa-ku, Yokohama 236-0001, Japan

The stratification of the equatorial thermocline is a key parameter for global climate since its changes can potentially affect the intensity, period and other properties of El Niño and the Southern Oscillation. The factors that control the equatorial stratification are currently not well understood. Using an idealized ocean general circulation model, Liu and Philander (1995, *JPO*; hereafter LP) showed that weakened westerly winds at midlatitudes strengthen the equatorial stratification. To modify equatorial stratification, higher-order baroclinic waves ($n > 1$) need to propagate from the forcing region (midlatitudes in the case of LP) to the equatorial region. Wind stress changes, however, preferentially force the first-baroclinic-mode ($n = 1$) waves. Then, how do wind changes induce higher baroclinic waves? Recent studies (Inui et al., 1999, *JPO*; Xie et al., 2000, *JPO*) showed that changes in the midlatitude westerlies lead to variations in the pathway of low potential vorticity (PV) water (also known as mode water). Subsurface temperature anomalies of higher baroclinic structure arise as a result of such pathway changes. The equatorward propagation of these anomalies of higher baroclinic mode structure has not been examined.

We repeated LP's experiments, focussing on how higher-order baroclinic waves are generated and propagate equatorward in light of new theoretical understanding. Under weakened westerlies (*WW* run) the subtropical gyre spins down and the northward western boundary current (WBC) weakens, leading to a shallow mixed layer in the eastward WBC extension. Because the low-PV Mode Water forms in a deep mixed layer, this shallowing makes "weaker" Mode Waters with higher PV, and hence the thermocline is more strongly stratified. This signal of stronger stratification propagates equatorward as higher baroclinic Rossby waves in direction of the mean gyre circulation, consistent with recent theoretical studies. After the waves arrive at the western boundary, they propagate equatorward as Kelvin waves and spread eastward along the equator, causing a stronger equatorial stratification. Results from more realistic simulations will also be presented.

OS31M-05 0940h

Vertical Structure of the Eastern Pacific North Equatorial Countercurrent

Sean C Kennan[1] (954.262.3637; skennan@nova.edu)

Janet Sprintall[2] (858.822.0589; jsprintall@ucsd.edu)

Pearn P Niiler[2] (858.534.4100; pniiler@ucsd.edu)

[1]Nova University Oceanographic Ctr., 8000 N. Ocean Dr., Dania Beach, FL 33004, United States

[2]Scripps Institution of Oceanography, Univ. of California, San Diego 9500 Gilman Dr. MC0230, La Jolla, CA 92093, United States

The earliest verification of the theory of wind-driven ocean circulation was based on its success in explaining the existence of the Pacific North Equatorial Countercurrent (NECC). Sverdrup showed that this large scale current running eastward against the prevailing winds was consistent with the wind stress curl of the doldrums. In summer 2001 we returned to the eastern Pacific to stage a modern experimental test of Sverdrup's theory for the NECC. Here we present observations of the three-dimensional velocity structure of the NECC and make preliminary estimates of the partition between directly wind-driven and geostrophic transports. The vertical structure of the current was observed using a combination of standard shipboard ADCP, a specially mounted high frequency ADCP, and a towed CTD seasoar package. Over 100 surface drifting buoys tracked the large scale structure of the surface current. We found the NECC to vary in intensity and vertical distribution during June-July across 20 degrees of longitude from 105-85W. The surface flow was relatively stronger, and broader (several hundred kilometers wide) compared to the steadier subsurface flow. Our preliminary results indicate that the NECC can be clearly separated into a shallow (<100m) mixed layer flow dominated by time-varying Ekman dynamics, overlying a geostrophic, pycnocline flow.

OS31M-06 0955h

Sverdrup and Nonlinear Dynamics of the Pacific South Equatorial Current

William S. Kessler[1] (206-526-6221; kessler@pmel.noaa.gov)

Gregory C. Johnson[1] (206-526-6806; gjohnson@pmel.noaa.gov)

Dennis W. Moore[1] (206-526-4146; dmoore@pmel.noaa.gov)

[1]NOAA / PMEL, 7600 Sand Point Way NE, Seattle, WA 98115, United States

The Sverdrup circulation in the tropical Pacific is constructed from satellite scatterometer winds, compared with measured ocean currents, and diagnosed in an ocean GCM. A new zonal velocity climatology, based on ADCP data mostly from cruises to service TAO moorings, provides well-resolved upper ocean zonal currents within 8°S-8°N, averaged over the 1990s. Previous depictions of the Sverdrup circulation near the equator have shown only weak vertically-integrated flows; here we show that the actual transports are not weak and investigate whether the discrepancy is due to inaccuracies in the wind forcing or to Sverdrup dynamics being too simple in this region. The scatterometer winds show a narrow, zonally-oriented strip of positive curl along the SST front north of the equator in the eastern Pacific. This feature was unresolved in previous coarsely-gridded wind climatologies. It occurs because of strong air-sea interaction over the cold tongue. Including this additional element of curl forcing greatly improves the realism of the Sverdrup representation, showing a strong SEC(N) and also eastward transport along the equator that was not evident in Sverdrup transports found from either ship wind or reanalysis wind products. However, although the new winds are qualitatively more consistent with the observed ocean circulation, the magnitudes of the equatorial transports (both eastward and westward) derived from them are still too weak by a factor of two compared with observed transports. An ocean GCM gives a more realistic simulation of the mean transports. Examining the effect of the model nonlinear terms through the vorticity balance shows that nonlinearities act to amplify the mean currents of the tropical Pacific, both the equatorial eastward transport and the westward off-equatorial transport.

OS31M-07 1030h

Effects of Equatorial Undercurrent on Turbulence and waves

Dailin Wang[1] (8089569489; wangd@soest.hawaii.edu)

Peter Muller[2] (pmuller@soest.hawaii.edu)

[1]International Pacific Research Center University of Hawaii at Manoa, SOEST-IPRC 2525 Correa Road, Honolulu, HI 96822

[2]Department of Oceangraphy University of Hawaii at Manoa, 1000 Pope Road, Honolulu

The effects of equatorial undercurrent (EUC) shear on equatorial upper-ocean turbulence and internal waves are studied using a large eddy simulation (LES) model, with an emphasis on the early stage of growth of nighttime convection, or deep-cycle turbulence. Numerical experiments are conducted using various shear profiles: (1) full background shear (EUC shear); (2) no background shear; (3) stable part the background shear only, namely velocity is constant for the depth range where Ri < 0.25 in experiment (1); and (4) unstable part of the background shear only, namely, velocity is constant for the depth range where Ri > 0.25 in experiment (1). It is found that flow evolution crucially depends on the background shear. Removal of all or part of the shear profile dramatically degrades the realism of the results. Convection in the mixed layer triggers shear instability, which in turn radiates gravity waves downward into the upper thermocline. Local shear instability can be triggered by downward propagating internal waves in a marginally stable environment. This local shear instability is the cause of mixing well below the mixed layer. When complete EUC shear is present, internal waves with wavelengths of 200-300 m are generated below the boundary layer, in agreement with observations and linear instability analysis. The total shear profile determines the characteristics of the waves. Turbulent kinetic budget and the role of these waves on turbulence are discussed.

OS31M-08 1045h

The Effect of Deep Ocean Temperatures on the Upper Ocean Heat Content in the Equatorial Pacific Ocean

Paul J Goodman[1] (845-365-8374; paulg@rosie.ldeo.columbia.edu)

Mark A Cane[1] (845-365-8344; mcane@ldeo.columbia.edu)

Daniel P Schrag[2] (617-495-7676; schrag@eps.harvard.edu)

[1]Columbia University - Lamont-Doherty Earth Observatory, PO Box 1000 61 Rte 9W, Palisades, NY 10964, United States

[2]Harvard University - Department of Earth and Planetary Sciences, 20 Oxford St, Cambridge, MA 02138, United States

The tropical thermocline is maintained by the competing forces of downward diffusion of heat from the surface and the upwelling of cold waters from below. To test the relative influence of these processes, we imposed a -3C temperature anomaly on the entire ocean (surface to deep) in a coupled model (LOAM) and analyzed the evolution of the sea surface temperature (SST) and the upper ocean heat content.

In the first experiment with no windstress feedback, the Western Pacific SST is very quickly restored to its pre-anomaly temperature due to a much reduced latent heat flux. The Eastern Pacific SST only partly recovers: the SST is 1-2C colder than the pre-anomaly value after 100 years. In the second experiment where the equatorial wind stress responds to the modelled SST anomaly, the western Pacific recovers more slowly and the trade winds are enhanced, similar to the cold phase of the ENSO cycle.

These experiments imply that the upper ocean heat content is largely controlled by surface processes, but the ENSO cycle can be affected by mid- and high-latitude subsurface water mass formation.

OS31M-09 1100h

The Tropical Atlantic Circulation Estimated From Altimetry Data With a Reduced-Rank Stationary Kalman Filter

Paola Malanotte Rizzoli[1] (617-253-2451; rizzoli@ocean.mit.edu)

Mark Buehner[2] (1-514-421-4735; Mark.Buehner@ec.gc.ca)

Tomoko Inui[3] (1-907-474-1556; tomoko@iarc.uaf.edu)

Antonio Busalacchi[4] (1-301-405-5599; tonyb@essic.umd.edu)

[1] Massachusetts Institute of Technology , Building 54, Room 1416 Dept. of Earth, Atmospheric and Planetary Sciences, 77 Massachusetts Ave., Cambridge, MA 02139, United States

[2] Meteorological Service of Canada , Data Assimilation and Satellite Meteorology Division 2121 Trans-Canada Hwy, Dorval, QC H9P 1J3, Canada

[3] University of Alaska, IARC 406-A1 930 Koyokuk Dr., Fairbanks, AK 99775, United States

[4] University of Maryland, ESSIC, 224 CSS Building, Room 2207, College Park, MD 20742, United States

A reduced-rank stationary Kalman filter is applied to a realistic model of the tropical Atlantic ocean. The goal is to estimate the sub-surface circulation and thermal structure for studies of the circulation pathways in the Atlantic subtropical and tropical gyres by assimilating Topex/Poseidon sea surface height (SSH) data.

The model is a reduced-gravity primitive equation of GCM of the upper ocean with a variable-depth mixed layer and a domain covering the Atlantic ocean between 30°N and 30°S. Wind stress and heat flux, calculated from wind speed and cloud cover provided by NCEP, are used to force the model at the surface. The assimilation scheme is an approximation to the extended Kalman filter in which the error covariances of the state estimates are only calculated in a reduced-dimension subspace spanned by a small number of empirical orthogonal functions (EOFs). Results from previous studies concerned with assimilating SSH in the tropical oceans suggest that the costly process of dynamically evolving the error covariances only results in minor improvements to the state estimates. Therefore, to obtain an assimilation procedure which only requires slightly more computational effort than a simple model integration, the asymptotically stationary error covariances are used.

Assimilation of simulated SSH data demonstrated the ability of the method to successfully constrain the circulation and sub-surface thermal structure. Assimilation of actual Topex/Poseidon altimetry data resulted in 23.6% reduction in the rms misfit with observed SSH relative to a pure model integration. Also, the agreement between the power spectra of the observed and model SSH is significantly improved by the assimilation. Evaluation of the impact on the subsurface fields is more difficult due to a lack of independent measurements. However, changes to the thermocline structure appear reasonable and the correlation between the observed SSH and the depth of the model thermocline are improved by the assimilation.

OS31M-10 1115h

Seasonal to Decadal Variability of the Tropical Atlantic Thermocline

Alban Lazar[1] (Alban.Lazar@lodyc.jussieu.fr)

Tomoko Inui[2] (tomoko@iarc.uaf.edu)

Antonio J. Busalacchi[3] (tonyb@essic.umd.edu)

Paola Malanotte-Rizzoli[4] (rizzoli@MIT.EDU)

[1] LODYC Univ. Paris VI, University Paris VI, Paris, France

[2] IARC-Frontier, University of Alaska, Fairbanks, Fairbanks, AK, United States

[3] Earth System Science Interdisciplinary Center, University of Maryland, College Park, College Park, MD, United States

[4] Massachusetts Institute of Technology, Boston, MA, Boston, MA, United States

Recent studies aimed at understanding the low frequency variability of the tropical oceans have hypothesized that oceanic teleconnections between the subtropics and tropics could constitute the oceanic component of slow coupled ocean-atmosphere modes. Most of the attention has been focused on the Pacific Ocean because of the importance of the El Nino/Southern Oscillation. However, the interannual to decadal variability of the tropical Atlantic Ocean is a strong signal, and provides considerable motivation for studying the physics of subtropical-tropical connections within this basin. This study assesses the main kinematic characteristics of the thermocline branches of the subtropical-tropical cells (STC) in the Atlantic Ocean. A series of ocean model experiments are used to study the seasonal cycle of subduction, entrainment, and subsurface circulation. The subduction rate, timing, and duration are contrasted for the Northern and Southern Hemisphere. These quantities, poorly known for the Southern Hemisphere, are essential since they quantify the main source water of the upper equatorial thermocline. The subsurface pathways are characterized using conservative quantities as well as releases of simulated Lagrangrian floats. On longer time scales the role of momentum versus buoyancy forcing are considered on and off the equator in the context of oceanic teleconnections.

OS31M-11 1130h

The Path of Antarctic Intermediate Water Across the Equatorial Atlantic

Markus W Jochum[1] (617 2531291; markus@ocean.mit.edu)

Paola Malanotte-Rizzoli[1] (Paola@ocean.mit.edu)

[1] MIT/Woods Hole Joint Program, 77 Massachusetts Avenue, Cambridge, MA 02139, United States

We used a slightly idealized configuration of a numerical ocean model to investigate how the Antarctic Intermediate Water (AAIW) crosses the equator in the Atlantic. We find that upon crossing the equator the Intermediate Western Boundary Current breaks up into eddies that have no signal in or above the thermocline. These eddies merge with the shallow retroflection eddy of the North Brazil Current (NBC)- North Equatorial Countercurrent retroflection at 7N to create NBC rings that reach well below 1000m depth. Futhermore we studied the intermediate depth flowfield along the equator. Based on available observations and our model results we reject the idea of strong zonal intermediate currents in the Atlantic. Instead we show that the notion of these intermediate currents is due to an undersampling of the strong annual and semiannual Rossby waves. The equatorial tracer distribution can be explained by Stokes drift and dispersion against the gradient of eddy kinetic energy.

OS31M-12 1145h

Observational Evidence for Flow between the Subtropical and Tropical Atlantic: the Atlantic Subtropical Cells

Dongxiao Zhang[1,2] ((206)526-4184; zhang@pmel.noaa.gov)

Michael J. McPhaden[2]

William E. Johns[3]

[1] Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA 98115, United States

[2] NOAA / Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115, United States

[3] Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, United States

An analysis of available hydrographic data in the Atlantic between 1950-2000 is carried out to determine the pathways of thermocline water from the shallow subtropical subduction regions to the tropics. The goal of this study is to describe and quantify these pathways using potential vorticity, salinity, and geostrophic and Ekman flow estimates, and to assess subtropical-tropical interaction in the thermocline and its interaction with the deep thermohaline overturning circulation in the Atlantic. In both hemispheres, the subducted Salinity Maximum Waters flow into the tropics in the pycnocline along both interior and western boundary pathways. The North Atlantic ventilating trajectories are confined to densities between about 23.4 to 26.0 σ_θ and only about 2 Sv of water reaches the tropics through the interior pathway, while the western boundary contributes about 3 Sv to the equatorward thermocline flow. The pathways skirt around the potential vorticity barrier and reach their westernmost location at about 10°N. In the South Atlantic, about 10 Sv of thermocline water reaches the equator through the interior (4 Sv) and western boundary (6 Sv) in the same range of densities as in the North Atlantic, but weighted toward a slightly higher mean density. The ventilation pathways are spread over a much wider interior window in the Southern than in the Northern Hemisphere, which at 6°S extends from 10°W to the western boundary. The equatorward convergent flows in the thermocline upwell into the surface layer and return to the subtropics through surface poleward divergence. As much as 70% of the tropical Atlantic upwelling into the surface layer is associated with these subtropical circulation cells, with the remainder contributed by the warm return flow of the deep thermohaline overturning circulation.

OS31N HC: 318 B Wednesday 0830h

Bentho-Pelagic Coupling at High Latitudes I

Presiding: **C Smith,** University of Hawaii at Manoa**; D DeMaster,** North Carolina State University

OS31N-01 0830h INVITED

Benthic-Pelagic Coupling in the Coastal Waters of Antarctica

Andrew Clarke (+44 1223 221591; andrew.clarke@bas.ac.uk)

Andrew Clarke, Biological Sciences Division British Antarctic Survey High Cross Madingley Road, Cambridge CB3 0ET, United Kingdom

The coastal waters of Antarctic typically exhibit an intense but highly seasonal pulse of primary production. A four-year time-series of chlorophyll (size-fractionated at 20, 5, 2 and 0.2 microns) measured weekly, and feeding activity in 13 taxa of benthic suspension feeders measured twice-monthly by SCUBA divers, has provided new insights into benthic-pelagic coupling at high latitudes. The intensity and timing of the summer phytoplankton bloom varies between taxa (and hence size fractions), and is also highly variable between seasons. The timing of feeding activity in the benthos depends on the temporal pattern of availability of the particles selected, with taxa taking small cells having longer feeding periods than those taking larger cells (especially diatoms). Carnivorous taxa feed year-round, though feeding intensity decrease in winter. These data show that the seasonality of primary production exerts a major control on the biology of consumers, but that this seasonality becomes less intense at higher levels in the Antarctic food-web.

WED

OS31N-02 0900h

FOODBANCS on the Antarctic Peninsula Shelf: The Benthic Food Bank Hypothesis and the Seasonal Deposition Pulse

Craig R Smith[1] (808-956-8623; csmith@soest.hawaii.edu)

Sarah L Mincks[1] (smincks@soest.hawaii.edu)

Adrian G Glover[1] (aglover@soest.hawaii.edu)

David J DeMaster[2]

Paulo Y Sumida[3]

[1] University of Hawaii at Manoa, Dept of Oceanography 1000 Pope Rd., Honolulu, HI 96822, United States

[2] North Carolina State University, Dept of MEAS, Raleigh, NC 27695-7514, United States

[3] Instituto Oceanogrfico da Universidade de So Paulo, Depto Oceanografia Biolgica Praa do Oceanogrfico, 191, Sao Paulo, SP CEP 05508, Brazil

Primary production and biogenic particle flux on the Antarctic shelf exhibit extraordinary seasonal variability. This intense boom-and-bust production cycle may profoundly affect food availability and life-history strategies of shelf benthos. We hypothesize that much of the new production from the intense Antarctic summer bloom deposits rapidly onto the shelf floor where it degrades very slowly, providing a persistent "food bank" for detritivores. To test this hypothesis, we have conducted a seasonal study of the flux and fate of bloom phytodetritus at the West Antarctic Peninsula shelf floor, called **FOODBANCS** (**FOOD** for **B**enthos on the **A**ntarctic **C**ontinental **S**helf). Using sediment traps, core sampling, radiochemical profiles, and bottom photography, we evaluated temporal variability in the flux and inventory of bloom detritus on the west Antarctic Peninsula shelf, and benthic biological responses, in Nov 1999 (shortly pre-bloom), Mar 2000 (shortly post-bloom), Jun 2000 (end of the ice free period), Oct 2000 (end of winter-ice period) and Feb 2001 (shortly post bloom).

Sediment traps (moored 150 mab) indicate 5-fold seasonal and 10-fold interannual variability in the flux of POC and chloropigments to the seafloor during our study period. The intense seasonal pulse of phytodetritus can create a green carpet covering broad areas of the Peninsula shelf; seafloor surveys indicated a carpet in Feb 2001 covering at least 35,000 km^2. However, even with the phytodetrital carpet, seafloor inventories of chloropigments (and a variety of biomass parameters) were relatively constant at all sampling times, suggesting a persistent food bank for detritivores in Antarctic shelf sediments. This persistent food bank